MAGNETIC OXYGEN ANALYZER of the indicating type. The range of oxygen removal covered is 0 to 33 per cent.

The Magnetic Oxygen Analyzer in Studies of Oxygen Uptake

A New Instrument for Measuring Aerobic Oxidation Rates

by **SAM R. HOOVER, LENORE JASEWICZ, *and* MANDOR PORGES, *U.S. Dept. of Agriculture, Eastern Regional Research Laboratory, Philadelphia, Pa.***

THIS report presents a simple procedure for measuring oxygen uptake from the gas phase that appears to have great utility in both research studies and the control of aerobic treatment processes.*

The instrument employed was the magnetic oxygen analyzer developed by Linus Pauling and associates[1] for the armed services during World War II, commercial models of which are manufactured by Arnold O. Beckman, Inc.**

The model C instrument with an operating range of 100-160 mm. was designed for physiological studies. This range covers oxygen removals of 0.33% at ordinary atmospheric pressures with an accuracy of ± 1% of scale range, or about ± 0.1% O_2, and is therefore well suited to the study of aerobic fermentation processes. It is an indicating analyzer; recording models are available but were not used in this study.

The principles and applications of oxygen recorders in industry were reviewed recently by Riggs[2], but the present application to measurement of oxygen removal in biochemical oxidation processes was not discussed.

How the Analyzer Operates

The basic principle involved is that oxygen is the only common paramagnetic gas; that is, it is attracted into a magnetic field. A tiny glass dumbbell filled with nitrogen or oxygen is suspended between two pairs of magnetic pole tips by a stretched quartz torsion fiber. The oxygen in the gas stream is attracted to the area between the poles, thus displacing the dumbbell. The dumbbell rotates in the magnetic field to an equilibrium position dependent on the magnetic rotational force and the torsional force of the quartz fiber. A mirror attached to the dumbbell indicates the equilibrium position by reflecting a light beam on a calibrated translucent scale. In the recording apparatus, an electrostatic compensation is used to maintain a null-point balance. The balancing electrostatic force is converted by a unique system into a potential that can be recorded on commercial recording potentiometers[3].

The gas sample is passed continually through the apparatus, which has a capacity of 9 cc. at any flow rate between 50 and 260 cc/min. Water vapor dilutes the oxygen, and

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** The mention of products does not imply endorsement or recommendation by the Department of Agriculture over other products of a similar nature not mentioned.

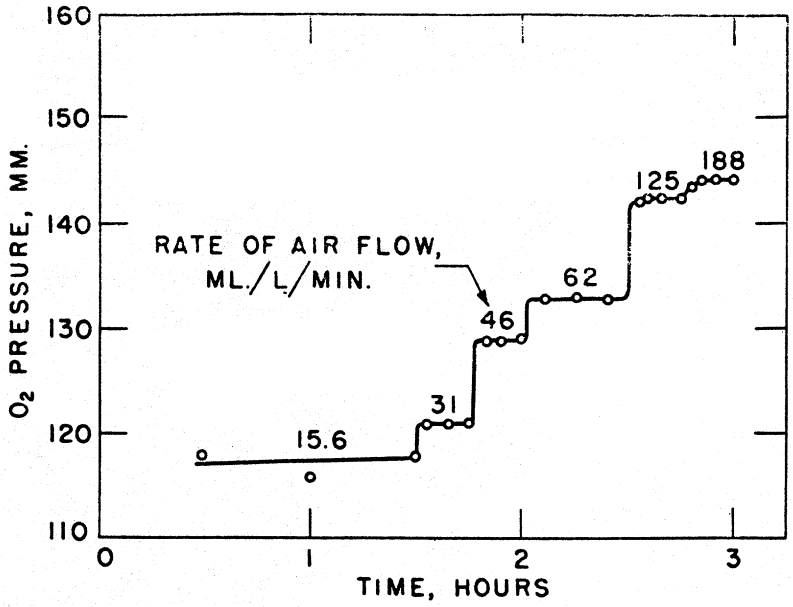


Fig. 1—CONSUMPTION of oxygen from air supplied to synthetic milk waste

therefore samples must be either wet or dry.

In the work reported here, the compressed air used was passed through water at the operating temperature of the aerator and sampled intermittently to determine the O_2 content of the air. An alternative procedure was to pass the air through the aerator at extremely high rates to get the control value. The gas sample was removed from the aerator by an inverted funnel with the rim just below the surface of the liquid. The outlet of the oxygen analyzer vented the gas at atmospheric pressure. A noteworthy feature of this system of analysis is that the oxygen transfer in the liquid is given directly by dividing the decrease in O_2 pressure by the observed pressure of the control.

Design of Experiment

A stable, balanced, aerobic flora was established which oxidized at a high rate a synthetic milk waste consisting of a 0.1% solution of skim milk in water. The aerator was a Humfeld type[3], with an inverted funnel at the liquid level to catch the sample of gas coming off the surface. The compressed air supplied to the system was passed through a dust trap and a calibrated flowmeter. The effluent gas sample was similarly measured and passed through the oxygen analyzer. The other conditions of the experiments were the same as those described previously[4]. Vigorous agitation and mixing of the solution with accurate control of temperature and aeration, essential features of this study, are readily obtainable in this equipment.

After several exploratory runs, the oxygen removed by the culture was measured as a function of the rate of air flow into the system. The purpose of the experiment was to test the utility of this type of measurement; no attempt was made to obtain optimum rates of biochemical oxidation.

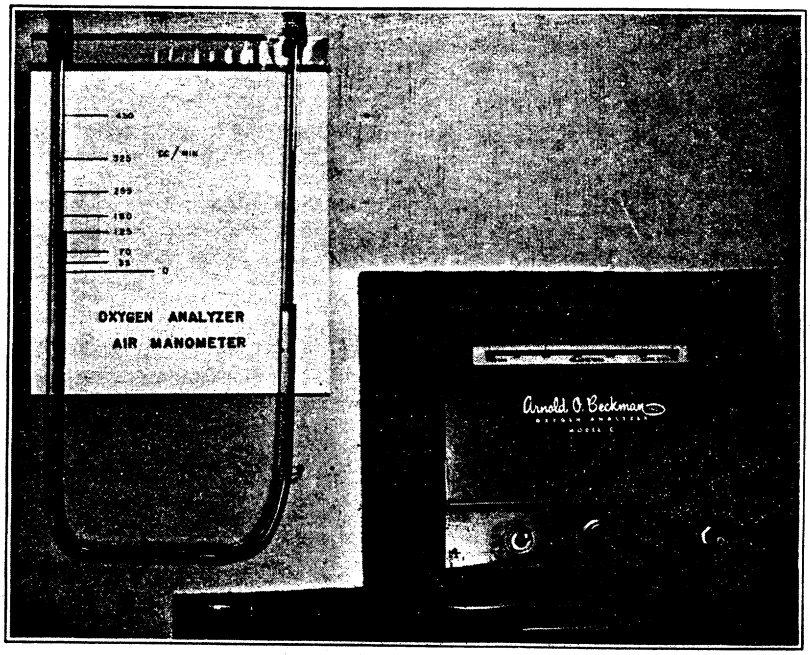
Procedure and Results

It was difficult to get steady readings of O_2 pressure in the effluent gas at extremely low air flow. After some adjustments of the rate, however, the system stabilized at about 118 mm O_2 pressure at 15.6 ml/L air flow (250 ml/16 L). The data of Fig. 1 were then obtained within a 2-hour period. The response of the instrument to a change in air supply was rapid; a new equilibrium position was reached in 2 to 3 minutes, the time required to flush the system. The data are given in tabular form (Table 1) to show the simplicity with which the O_2 transfer and the rate of O_2 utilization can be calculated.

The low rate of oxygen uptake at the lowest air flow is noteworthy. Although 21% of the oxygen was taken from the air stream, leaving 79% unused, yet it is apparent that the bacterial cells were receiving insufficient oxygen. The dispersion of air was not adequate to maintain aerobic conditions; the instability of readings already referred to undoubtedly reflect this unbalanced biological situation. Satisfactory steady-state conditions were maintained at the higher rates of aeration, as shown by the fact that the rate of uptake varied only between 1.6 and 1.9 for a 6-fold increase in rate of aeration.

Graphical Solution is Designed

The constant rate of oxidation on a volume or a weight basis, if adequate air is supplied, was predicted from previous studies, wherein the rate of oxidation was constant above about 0.5 ppm dissolved oxygen[5]. This fact makes possible an algebraic or graph-



CALIBRATED FLOWMETER and oxygen analyzer set up employed
The effluent gas sample flow was measured and oxygen consumption was determined

ical solution of the data, as illustrated in Fig. 2. Inasmuch as the O_2 consumption is independent of rate of aeration, the transfer efficiency times the amount of O_2 supplied is a constant.

This is the equation of a simple hyberbola $xy = k$, and plotting y, oxygen transfer against 1/x, the reciprocal of the rate of aeration, produces a straight line with a slope k, which is proportional to the rate of O_2 uptake. The abscissa of Figure 2 is in terms of air flow: for calculation of O_2 uptake it must be converted to oxygen flow. The abscissa is therefore divided by 149 5/760 or 0.197 to obtain the slope of the line in terms of oxygen uptake. A resultant value of 1.23 ml O_2/L/min. is obtained, which multiplied by 32/22.4 equals 1.76 ppm O_2. This value can be compared with the mean of the last 5 values in column 4 of table I, which is 1.79. Thus the graphical and arithmetical solutions agree excellently. The marked deviation of the point of the lowest aeration rate is again evidence of a failure to supply adequate oxygen to the microorganisms.

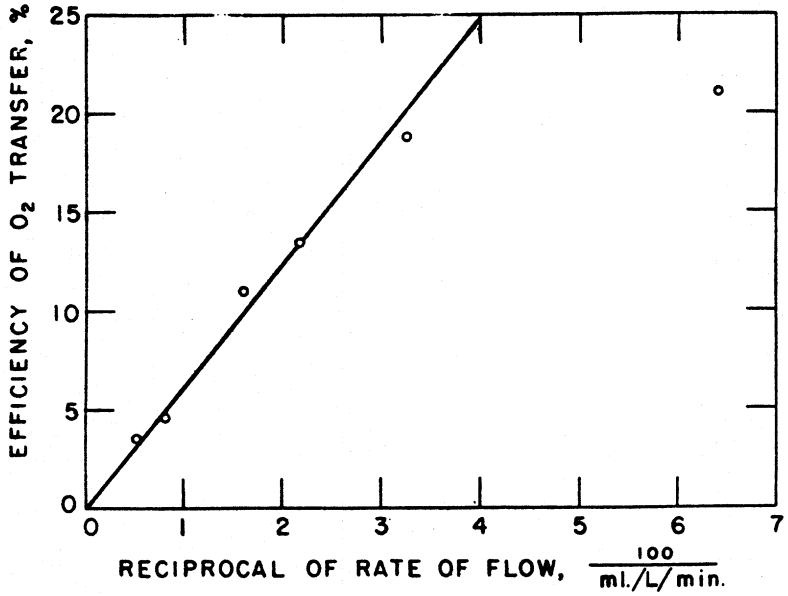


Fig. 2—Oxygen transfer efficiency vs. reciprocal of rate of flow

A constant rate of oxygen utilization is indicated by the linear relation from 0 to 3 units. The point at 6.4 units shows that the oxygen requirement is not satisfied

Oxidation Rate Breakpoint

Fig. 2 has an additional value for research purposes in that the "breakpoint" at which the air supply becomes insufficient is clearly shown. The direct plot of oxygen transfer vs rate of air flow (not shown) is more difficult to interpret, for the hyperbolic function is changing rapidly in the critical region, and the point where the air supply becomes insufficient is not apparent.

In biochemical research, the rate of oxidation per unit of cell tissue present is an extremely valuable parameter. This rate, called the oxidation quotient, QU_2, is readily calculated from the data obtained if a determination of cell dry weight is made. The determination was inadvertently not made in the experiment cited, but other determinations on similar studies indicate there were about 2500 ppm cell solids present. The increase in amount of cell tissue during the experiment was also neglected in this calculation, but an increase of more than 10% in weight in the 2-hour period during which the data were obtained would not be expected. The tabulated values are therefore satisfactory for comparison with related data and for illustration of the utility of such measurements.

Discussion

The experiment performed illustrates the valuable data obtainable on an aerobic oxidative system by use of O_2 analysis. The activity of the activated sludge floc and the performance of the air-dispensing system can both be determined almost instantly Such information is essential in research studies. In routine control of plant operation, it would seem that this type of analysis would have great value, for it could easily be used as a constant record of plant performance, a record that would show directly whenever the system went out of balance. The instrumentation required to convert this measurement to a recording-controlling system would not be difficult; the air supplied to the activated sludge plant could be controlled to maintain an O_2 content of the effluent gas within a definite range. At times of low oxygen demand much less air would be pumped into the system with resultant economy in the power required.

The utility of such measurements is not restricted to sanitary engineering; they could be applied in fermentation plants using aerobic processes for the production of antibiotics, vitamins, and food and feed yeasts. The comments above can be applied directly in this whole field of aerobic biochemical processes.

In this short presentation, the emphasis has been placed on the utility of the magnetic oxygen analyzer in a biochemical study of sanitary engineering processes. Those who are interested in the broader phases of this work are referred to a recent review[6] of the research on aerobic treatment of dairy waste carried out in this laboratory.

Table I

OXYGEN CONSUMPTION BY 16 L OF AERATOR CULTURE AS A FUNCTION OF AIR SUPPLY

Air Flow	Oxygen Utilization			
ml/L/min. (Col 1)	mm (Col. 2)	% (Col. 3)	ppm/min. (Col. 4)	ml/gm/hr (Co . 5)
15.6	31.5	21.1	0.92	15.6
31.3	28.0	18.7	1.65	27.7
46.9	20.5	13.7	1.81	30.8
62.5	16 5	11 0	1.94	32.6
125	7.0	4.7	1.65	27.9
188	5.25	3.5	1 86	31.5

Data in Column 3 were calculated by dividing (2) by the 0s content of influent air, 149.5 mm.

Data in Column 4 were calculated as follows: $(4) = \frac{(1) \times (2)}{760} \times \frac{32}{22.4} =$

$(1) \times 2) \times 1.88 \times 10^{-3}$ ppm 0_2/min.

The actual atmospheric p essure should be used for most accurate results.

Gas law corrections for tempe ature (30 C) were not made.

Data in Column 5 were calculated on basis of 2500 ppm solids present. This value is an approximation (see text).

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